A Textbook of
ENGINEERING MATERIALS

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PREFACE

This book is the outcome of my experience gained while dealing with the manifold aspects of the topics covered both in the teaching as well as in the practical fields. Its preparation was undertaken to meet the need in the engineering eduction and profession which was felt for a general textbook covering the manufacture. properties and uses of the most common materials of engineering construction in a comparatively concise and thoroughly modern manner.

This book on engineering materials is designed for use as a textbook to the students pursuing engineering and technical education in the Engineering Universities. Engineering Colleges. Polytechnic Institutes and other Technical Institutions. Industrial as well as structural properties and application of various important locally available engineering materials are described and hence this book is a unique offer to the students of all branches of engineering, the practicing engineers, architects and to those preparing themselves for AMIE (Bangladesh) Examination. The treatment of various classes of materials follows a general systematic pattern which has been made uniform through-out so far as has been found practicable. The consideration of each material is prefaced by and introduction and general discussion of its applications in engineering constructions, followed by a study of its manufacture or natural occurrence, and concluded by a discussion of physical and mechanical properties in relation to its uses.

This book aims at presenting in a simple, concise and lucid form the best of the most upto-date knowledge concerning materials use in all types of engineering construction in Bangladesh. Numerous illustrative diagrams. worked-out examples. tables. charts and graphs have been presented in this book to enable the requiring no previous knowledge in this field.

The author cannot make a pretence of being a specialist in all of fields which are converted in various chapter of this book. This work is, therefore, to a large degree a compilation of data and opinion from a great many different sources. The author takes pleasure in acknowledging his great indebtness to the large number of engineers, architects, government officials, and manufacturers who have privately or by their writings contributed much to make up this volume. Care has been taken to give accurate information in this text book; however, in a subject so varied as Engineering Materials, mistakes may occur. I will appreciate having errors called to my attention. Any suggestion for future improvement would be graciously welcomed.

The author is deeply grateful to Dr. A. Hasnat, Professor and Head, Civil Engineering. Department. Bangladesh University of Engineering and Technology, Dhaka, for his kind encouragement in writing this book. Thanks are due to Dr. S. H. K. Eusufzai, Dr. A. Hannan, Al-haj A. F. M. Abdur Rauf, Dr. M. Shahjahan, Dr. J. R. Chowdhury, Dr. A. Salam, Dr. A Habib, Mr. Shamimuzzaman and Prof. Ali Akber of Civil Engineering Department for their interest, encouragement and valuable assistance in writing this book.

I wish to express my gratitude to my wife, Saleha, for her unfailing inspiration support and help during writing and in the final preparation of the book. Finally, sincere appreciation is extended to my family for allowing me to take so much of their time to write this book.

The author also thanks his publisher for kind co-operation and help in bringing out this book in time inspite of lost of difficulties.

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1

Introduction

1.1 General Consideration : Any material which has got application in engineering constructions is termed engineering material. In all branches of engineering, and understanding of the fundamental nature of engineering materials is becoming increasingly vital. Not only are requirements for materials for engineering applications growing more complex, but there are more materials to choose from every day. The engineer can no longer be satisfied with a superficial knowledge of a fees standard properties of a few commonly used materials. So many variation in properties are available that the engineer must have more basic understanding of the behavior of materials. This understanding can be developed only through a knowledge of the properties of the materials.

A bridge or a dam or a building or a road is to be built, and the choice of materials is up with the engineer. Shall steel or concrete be selected, or are there newer materials that might prove superior? The choice must be based on several factors; availability of materials, economy, ease of handling and fabrication, strength, durability and workability.

A civil engineer engaged in the task of planning, design and construction of building bridge, dams, roads, water purification plants, sewage treatment plans, airfields, or any other structure, should be thoroughly familiar with the desired engineering materials and their properties. Every engineering construction (structure) must be sufficiently strong and durable to resist the action of external forces and internal stresses due to various types of loads. In order to achieve maximum economy, the engineer must know the

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strength characteristics of the materials and the permissible stresses in each case.

A structure must be a harmonious blend of beauty strength utility and economy. To achieve this, specification for engineering materials must be laid down. A specification for an engineering material supplies a set of statements of requirements which the material should conform to in order to be acceptable for use in structure. In all engineering constructions, it is imperative in the interest of the safety and the durability of the structure that only materials of the acceptable quality and strength be used. Therefore, the engineer and other related personnel must have to acquaint themselves thoroughly with the functions and qualities of engineering materials, because upon the quality of engineering materials, depends the quality of structures. The quality control of all engineering materials is of prime importance to improve the quality of engineering constructions as a whole.

1.2 Properties of Engineering Material : A quality that defines a specific characteristic of a material is termed as a property. The properties of a material provide a basis for predicting its behaviour under various conditions. They are the tools the engineer uses to solve his material problems. Some of the most important properties of engineering material are :

1. Physical Properties	:	Size, Shape, density, porosity, structure.
2. Mechanical properties	:	Strength, elasticity, plasticity, stiffness, ductility, malleability, hardness, brittleness, resilience, creep.
3. Chemical Properties	:	Corrosion resistance, acidity, alkalinity, chemical composition.

4. Thermal Properties	:	Specific heat, thermal expansion, conductivity.
5. Magnetic Properties	:	Permeability, cohesive force, hysteresis.
6. Electrical Properties	:	Conductivity, dielectric permitivity, dielectric strength.

Fundamentally, the properties of a material depend on the nature of that particular material alone. Nearly all those properties listen, however, are also inseparably tied in with conditions of use environment and the state of the material. The actual evaluation of a property depends on all these factors. Mechanical strength, for example, differs for various forms of loading, and is commonly expressed by such terms as *tensile strength, compressive strength, or fatigue strength.*

Most properties of engineering materials must be evaluated entirely by experiment : certain specific conditions are applied and the corresponding properties are measured. Experiments for determining properties of engineering materials are usually called tests. Tests may provide properties for use in design or information on the quality of a material. The procedures are usually standardized because if identical procedures are always followed the results of a number of tests may be compared with some assurance. Much of the standardization is done by the national organization set up in each country to improved the use or materials in engineering constructions and also in industries. Some of these organizations are (1) BSI (British Standard Institute), (2) ASTM American Society of Testing Materials, (3) AASHO (American Association of State Highway Official), (4) ACL (American Concert Institute). Each organization gives standard test methods of all kinds in addition to standard specifications for materials and standard definitions of terms.

The following are the very important properties of engineering materials :

- **(1) Strength** : It is the property of material that represents its ability to resist internal forces or stresses. The three basic strengths of a material, the type of force to which the materials is to be subject, must be known. As for example the compressive and tensile strength of structural steel are nearly equal, whereas cast iron can take more compression and it is weak in tension. Similarly, concrete is very strong in compression but very week in tension.

Stress : Stress is the intensity of internal force developed when an external force is applied on an engineering material. It is denoted by the following expression.

$$S = \frac{P}{A} \qquad 1.1$$

where S is the stress, P is the external force applied and A is the cross-sectional area of the surface on which the force P is applied. Stress is usually expressed is psi (pounds per square inch). There are three types of stresses, . **(a) compressive stress, (b) tensile stress and (c) shear stress.**

Trensile Stress : This type of stress is induced in an engineering material when it is subjected to a tensile force.

Compressive Stress : This type of stress is induced in an engineering material when it is subjected to a compressive force.

Shear Stress : When a part of an engineering material tends to slide over another portion at a given section, the fibres at the section are side to be shear.

$$\text{Shear stress} = \frac{\text{Shear load}}{\text{Are under shear}} \qquad 1.2$$

Strain : When load (external force) is applied to a material not only a stress is induced in the fibres, but the size or the shape of the material is also changed. Strains the geometrical deformation of a material due to application of an external force. In other words, strain is a measure of the

deformation produced by the application of external force. It should be noted that the value of the strain is not expressed in any dimensional unit. Strain is denoted by the following expression :

$$e = \frac{x}{L} \qquad 1.3$$

where e is the strain, x is the extension or shortening of length and L is the original length.

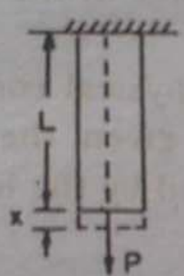

Fig. 1.1

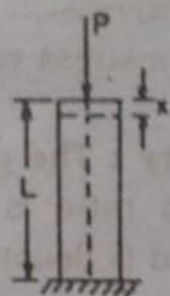

Fig. 1.2

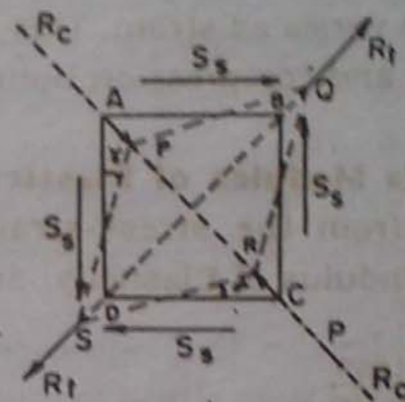

Fig. 1.3

Strains are again three types : (a) tensile strain, (b) compressive strain and (c) shear strain.

Tensile, stain, $et = \frac{\text{Extension of length}}{\text{Original length}}$ (Fig. 1.1) 1.4

Compressive stain, $ec = \frac{\text{Shortening of length}}{\text{Original length}}$ (Fig. 1.2)

1.5

Shear Strain : Shear strain is concerned with the change of shape or deformation resulting from the shear stress. The element ABCD shown in the Fig. 1.3 is subjected to shear stress. The rhombus PQRS is the deformed sheape of the square element ABCD caused by the shearing stress Ss. The value of shear strain is given by 2α.

(2) Elasticity : It is a property of a material which allows it to return to its original shape and size after the load to which it is subjected is released. This is a very important property of engineering materials. The strain for a given of load during the unloading process is equal to the strain for the same value of load during the loading process. A limiting

value of load will be found at which the strain does completely disappear with the removal of the load. The value of stress corresponding to this load is called the **Elastic Limit.** It was discovered by Hooke that if a material loaded without exceeding the elastic limit, then the deformation produced is proportional to the load production it. From the expressions of stress and from Hooke's law it can be said that stress varies as strain. This expression will equally apply in tension and compression upto a stress value at the elastic limit.

Youngs Modules of Elasticity : The physical constant obtained from the stress-strain ratio is given the nme, Young's Modulus of Elasticity, and is denoted by the letter E as follows :

$$E = \frac{\text{Stess}}{\text{Strain}} \qquad 1.6$$

Hooke's elastic law holes also in the case of shear streams and shear strain but the value of this ratio differs from that obtained in tension and compression and is termed as the 'shear modules' of the given material. Since the value of strain is expressed as a number, the units of E will be as same as that of stress. It should be noted carefully that Young's Modules has no significance beyond the elastic limit.

Modules of Rigidity : It can be defined as the ratio of the shearing stress to shearing strain; or

$$G = \frac{\text{Shearing stress}}{\text{Shearing strain}} \qquad 1.7$$

where G is the modules of rigidity.

Bulk Modules : This elastic constant expresses the relationship between the volumetric strain caused by direct forces. it is denoted by the letter K.

$$K = \frac{\text{Direct stresses cusing a change in volums}}{\text{Volumetric strain}} \qquad 1.8$$

Poisson's Ratio : If a direct force acts on a body, it produces direct strain in the direction of its action and an

opposite kind of strain in every direction of action. This is know as lateral strain while the strain, in the direction of action of the force is known as longitudinal stain. The ratio of these two kinds of strain is a constant and is know s Poisson's Ratio. It is generally denoted by μ.

μ = \f(Lateral strain. Longitudinal strain 1.9

(3) **Plasticity** : Plasticity is the opposite property of elasticity. A perfectly plastic material does not return to its original shaper and size when the load causing deformation is remove. Lead is an example of plastic material.

(4) **Malleability** : This property permits plastic deformation of a material when subjected to compression. Materials that can be hammered into thin sheets are malleable materials.

(5) **Brittleness** : The opposite property of malleability is brittleness. Cast iron is an example of brittle material.

(6) **Stiffness** : The term stiffness designates the resistance of a materials to deformation in the elastic range. Stiffness of ductile material is measured by the modules of elasticity.

(7) **Ductility** : Ductility indicates the ability of a material to deform in the plastic range without breaking. No accurate measure of ductility exists. For comparative purposes. however, ductility is usually defined by the percentage elongation of a tensile specimen at fracture for a specified length.

(8) **Toughness** : This property matures the ability to absorb to release energy in the plastic range.

(9) **Fatigue** : Certain materials are very often subjected to repeated stress.The term fatigue (fatigue strength) of a materials is used to indicate its strength in resisting repeated stress.

(10) **Hardness** : The term hardness, when used as a technological property of materials. is primarily associated with the surface. An appropriate definition of hardness is

the resistance of a material to permanent deformation of its surface. This deformation may be in the form of scratching, mechanical wear or cutting.

(11) Resilience : The resilience of a material is its ability to absorb energy in the elastic range. It is measured by the energy per unit volume required to stress a material in tension form zero stress to the proportional limit.

(12) Creep: In many applications, engineering materials are required to sustain steady loads for long periods of time. e.g. R.C.C (reinforced cement concrete) beams, columns, etc. Under such conditions the material may continue to deform until its usefulness is serially impaired. Such time-dependent deformations may be almost imperceptible, but over the life time of a material or structure they can grow large and even result in final fracture without any increase in load.

Under short-time loading, as in the conventional compression test, of a material there is an initial deformation that increase simultaneously with the load, s shown in the static stress-strain diagram. If under any conditions, deforatmion continues when the load is held constant, this additional deformation is termed as creep. In fact, creep is the time-dependent part of the strain resulting from stress.

1.3 Selection of Engineering Materials : Selection of materials for engineering applications depends first upon their properties in relation to intended use. The engineer should be alert for new materials that may be developed but he should also keep his mind receptive to possible new ways of using existing materials.

The next important considerations are economy and availability. Preference should always be given-to the locally available materials. Sometimes, a material must be selected even though inferior properties, because the right material is not locally available or too expensive.

1.4 Engineering Materials Commonly use in Bangladesh : The following are the important engineering materials that are commonly used in Bangladesh.

Stones, brick and other structural clay products, lime, cement, surki, and sand, concrete, iron, steel, ferrous alloys, non-ferrous metals and alloys, timber and timber products, bamboos, soils, bituminous materials, glass, plastic, paints, and varnishes, rubber, etc.

The important features of all the engineering materials with respect to availability, manufacture, desirable properties, standard specifications and uses in engineering constructions and in industries are discussed thoroughly in following chapters.

Questions

1. What is an engineering material? Critically examine the importance of engineering materials in engineering construction. Do you think that paper, water, air and ink can be termed as engineering materials? Justify your answer.

2. What do you mean by the term "Property" of a material? Why it is very important? Enumerate various properties of engineering materials.

3. Define the following : Stress, Strain, Elastic limit, Young's Modules of Elasticity, Modules of Rigidity, Poisson's Ratio, Malleability, ductility, Fatigue, and Hardness.

4. What are the important considerations that are looked for selecting engineering materials? Name the engineering materials commonly used in our country. Enumerate the specific uses of any ten of them.

Building Stones

- **2.1 Introduction :** A building stone is obtained from the rocks in the earth-crust.. It is a naturally occurring substance. Stone is considered to the king of engineering materials, and where durability and permanency of a structure are required, it continues to enjoy its superiority over all other rival materials of engineering construction. Stones were used in early days for structural works. Important historic examples of the uses of stones are the TajMahal, Buddhist Temples and Kutub Minar in India, the Pyramids of Egypt, the remains of Greecian and Roman structures and many other massive and beautiful structures found practically throughout the world. The main censer of extensive use of stone is that when selected properly, it has less wear and tear and does not involve much maintenance cost. Therefore, engineers must have thorough understanding of the characteristic properties of different types of stones available in their own country to ensure their proper and most beneficial application leading to the successful design and construction of structures.

To understand the properties of stones very thoroughly, one should study first the characteristics of stone-forming - minerals.

2.2 Minerals : The problems of civil engineering relate with foundation and again, foundation relates with rocks and soils. Since the rocks are nothing but the aggregates of minerals knowledge of minerals is essential first for civil engineers.

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Minerals are naturally occurring substances, having characteristics internal structures, and of more or less definite chemical composition and displaying more or less definite physical properties. They can be easily identified by the following properties :

1. **Streak and Coluor :** Th colour of a mineral is often of assistance in its identification. Streak is the colour of mineral in powdered form.
2. **Cleavage and Fracture :** The cleavage of a mineral is its capacity to split more readily in certain dircetions than in others, due to the arrangement of the atoms. Fracture of a mineral is the haphazard way the mineral breaks.
3. **Hardness :** The hardness of a mineral is measured by its ability to resist scratching. If a mineral is scratched by a knife, It is softer than the knife, If a mineral cannot be scratched by a knife, the two are equal in hardness or the mineral is the harder. If the knife is scratched by a mineral, the mineral is harder.
4. **Luster :** Luster is the appearance of a mineral in ordinary light.
5. **Structure :** Some minerals are granular, for example, olivine, others are fibrous, crystalline, etc.
6. **Specific gravity :** Specific gravity gives a very good basis for identification of minerals.
7. **Magnetism :** A few minerals are attracted by magnet, of these mineral magnetite is the most common example.
8. **Association :** The association of creation minerals with others is suggestive for identification of minerals.

Principal Stone forming Minerals : About 200 minerals have been recognized by the chemists and geologists but a few of them have got engineering applications. The following are the important rock forming minerals.

1. **Silica :** Quartz is a pure Silica. It is unaffected by weathering. Its colour may be white, grey, pink, purple or yellowish. Streak is white. No cleavage, luster is

vitreous and the structure is granular. It is hard and specific gravity is 2.66. It is used in the manufacture of bricks. ceramics. glass. concrete. mortar. plaster. etc.

2. **Feldspars :** Contains Silica. Alumina, Potassium, Sodium or Calcium. Generally two types :
   (a) **Potash Feldspars :** Also known as orthoclause. It contains Potassium, Alumina and Silica. Its colour is white. reddish. grey or grass. Streak is white 2 cleavage at 90°. luster is vitreous. granular in structure, very hard. sp. gravity is 2.5 to 1.7. It is used in the manufacture of porcelain wares. glasses and also for glazing.
   (b) **Lime-Soda Feldspars :** Also known as plagioclause. It contains Sodium. Calcium Alumina and Silica. Its colour is generally white, .may be grey, blush or reddish, Streak is white 2 cleavage at 90°. Luster is vitreous. structure is qranular or fibrous, very hard. sp. gravity is 2.4 to 2.85. It is used for manufacturing glasses, and ceramic products.
3. **Micas :** Complex Silicates of Potassium, Alumina, Silica. Magnesium and Iron, It is generally of two types :
   (a) **Muscovite :** Complex silicates of Potash, and Alumina. Its colour is generally white. yellowish or grey Steak is white. luster is vitreous, structure foliated very weak. one perfect cleavage, sp. gr = 3.0. It disintegrates very rapidly. hence a source of weakness is present in building stones.
   (b) **Biotite :** It is a complex silicate of Potassium, Magnesium, Iron and Alumina. Its colour is black. one perfect cleavage, luster is vitrous. Structure is foliated, moderatedly hard, sp.gr. = 3.6.
4. **Amphibole :** Also known as Hornblende. This is a complex silicate of Sodium, calcium, Magnesium, Iron and Aluminium, with a dark green to black colour.